DIRECTIONAL WIRELESS AS AN AID TO NAVIGATION.

For several years the Radio Research Board of the British Department of Scientific and Industrial Research has undertaken, under the directorship of Dr. Smith Rose, Ph. D., D., M. Sc., of the National Physical Laboratory, a systematic study on the variations of the apparent bearings given by wireless stations, and on the degree of accuracy these bearings are liable to yield.

This work, the results of which are of the utmost interest to navigators, since they have a direct application in marine and aerial navigation, has formed the subject of successive and detailed reports drawn up by the Radio Research Board; the nomenclature of these reports is given hereafter. But Dr. Smith Rose has summarized the aggregate results in an article written for the journal "Nature" (26th November 1927), from which the following is extracted :—

The application of wireless transmission as an aid to navigation is conveniently divisible into two parts according as the directive characteristic is applied at the transmitting or the receiving end of the wireless link.

I. *THE DIRECTIONAL RECEIVER OR DIRECTION-FINDER.*

When a plane vertical loop or its equivalent in space is rotated about its vertical axis, the electro-motive force induced in such a loop by an arriving stream of electromagnetic waves is proportional to the cosine of the angle between the plane of the loop and the direction of the waves so that the strength of the received signal varies from a maximum to a minimum or zero. The rate of change of signal strength with rotation is greatest at the minimum position, which is therefore always used for direction-finding.

(a) *Accuracy of Direction-finder.* There are several manufactured forms of direction-finder employing the above principle, and their accuracy when used under the best conditions may be said to be about 1°. Under most practical conditions, however, the instrument is subject to certain errors in determining the direction of a distant transmitter. In part these errors may be due to an actual deviation of the waves from their rectilinear path in crossing a coastal boundary, for example, when a maximum deviation of about 5° may be produced for wave-lengths of the order commonly used in marine directing-finding.

In the experimental work carried out at Orford, Suffolk, the coastal error on wave-lengths of 450 and 600 metres was found to be of the order of 3° or 4° when the direction of transmission was within 20° of the coast-line.

In every instance the error was such as to indicate a bending of the waves towards the normal to the coast-line in passing from the sea to the land side of the boundary. These experimental results are in complete agreement with those previously obtained by Eckersley.

More recently some experiments on the propagation of waves across a coastal boundary have been made by Baumler and Zenneck. Their results generally confirm those given above as to the magnitude and direction of the deviation of the waves in passing from sea to land.

It is worthy of note that, with the accumulation of experience of the use of direction-finders on board ship, it is now becoming customary to mark out on charts the "arcs of good bearings" of various transmitting stations, within which the results of observations are found to be reliable.

On the other hand, the errors may arise from the presence of local conditions near the direction-finder, such as trees, metalwork, and overhead wires, the current induced in which results in secondary fields being superimposed on the primary wave field and so produces a minimum signal in a false position of the direction-finder. As a result of several years' investigation these errors are now well understood, and in most circumstances they may be avoided or compensated for after reduction to a minimum.

(b) *Position of the Direction-finder.* In the application of direction-finding to marine navigation, a point of some debate has been the most desirable location for the instrument, on shore or on board ship. When erected in suitable surroundings, the shore direction-finder has an accuracy superior to that of the ship installation, for in the latter case the wireless bearing is taken relative to the ship, and reference must be made to the compass in order to determine the orientation of the ship at the instant the bearing was taken. Moreover, the ship direction-finder is subject to local error of a quadrantal nature due to the currents induced by the arriving waves in the metalwork, hull, stays, etc., comprising the ship itself. On the other hand, it is natural to find that the average ship's navigator does not care to entrust himself to the observations of an individual on shore with whom he is not in personal touch; and particularly at critical times in stormy or foggy weather, he much prefers to have the instrument on board ship and operated under his immediate control.

Furthermore, the ship, fitted with a direction-finder is enabled to take bearings upon the transmissions from other ships; and at least one instance can be quoted in which a ship in distress, after signalling its inaccurately estimated position, has been found at a position one hundred miles away by means of a direction-finder on the rescuing ship. A possible future development of the ship direction-finder is the provision of a safeguard against collision at sea in times of thick fog.

(c) *Conditions for Freedom from Night Errors.* It is now well-known that wireless direction-finders, even in the most favourable situations, are subject to a variable error under certain conditions of transmission, which chiefly occur at night. These errors are due to the reception of waves deflected in the upper atmosphere, which therefore arrive at the direction-finder travelling in a downward direction. So long as these waves are polarised with their electric force in the vertical plane of propagation, the true bearing will be read off on the direction-finder. But if, as is frequently the case, the plane of polarisation of these waves is rotated, then the resultant magnetic field produced at the earth's surface will not be perpendicular to the plane of propagation and an apparent error will be recorded on the instrument.

The actual value of the error will depend upon the relative magnitude of the down-coming waves and the waves transmitted directly along the earth's surface, since it is determined by the direction of the resultant magnetic field due to both sets of waves. Close to the transmitter the ground wave predominates and no error is produced.

The minimum distance at which night variations have been consistently experienced is about 30 miles for overland working, observations taken at closer ranges than this showing a maximum error of only 2° or 3°. MESNY has stated that night variations may occur for ranges of transmission as small as 15 miles, but according to Dr. SMITH ROSE's experience, night errors are small, although definite at such distances.

At a distance of about 30 miles overland, the strength of the ground wave has become reduced, and the angle of incidence and relative strength of the downcoming wave have increased sufficiently to introduce an appreciable error in bearing at night. Fortunately, for marine navigation, however, the attenuation of the ground wave is much less when travelling oversea and the downcoming wave does not become effective until the distance from the trasmitter is about 80 miles. Thus when, as is usually the case, the ship's direction-finder is operated on transmissions which are entirely across the open sea, the bearings are equally trustworthy by day or night up to distances of 80 to 100 miles.

It is now known that under such conditions direction-finding is sufficiently accurate for navigational purposes. Even in the presence of night errors their effect can be largely mitigated by taking a series of observations in succession over a period of a few minutes, when the mean bearing so obtained will be much more accurate than a single reading.

From various portions of the investigation in which it was possible to make a direct comparison between damped and undamped waves, it has been concluded that no effect attributable to the wave-damping has been observed. In the experiments on the wave-lengths employed for marine navigation, no undamped wave transmissions could be obtained entirely oversea, but in overland working the errors and effects encountered were of the same order for damped, undamped, and interrupted undamped waves. At a later date, it may become possible to repeat the comparison under conditions more closely allied to those used for navigational purposes.

An important factor to be noted from a navigational point of view is that of any effect of fog on direction-finding, since it is chiefly during foggy weather that the majority of direction-finding stations are called into action. On several occasions the author has taken particular notice of the existence of fog at times when observations were in progress, with a negative result. On one occasion in particular the fog was spread over the British Isles and a large portion of Western Europe, but the directional variations showed nothing beyond the usual day and night effects. These results form a confirmation to the observations of ROTHÉ, who concluded that no variations in ordinary atmospheric conditions would account for the small variations in bearings observed in the daytime.

FIXED BEACON STATIONS.

Concurrently with the development of the radio direction-finder on board ship, there was proceeded with the establishment of radio beacons, or fixed transmitting stations which send certain code signals automatically when once set in operation. The majority of these stations are located on light vessels or near shore lighthouses in the vicinity of the chief harbour entrances. Each station has a characteristic signal easily recognised by an untrained ear and distinctive from any other in the vicinity, and all the stations are clearly marked on charts at points well known to navigators, so that a radio bearing can be definitely identified and plotted on a chart with the same facility as a visual bearing.

A number of these stations are already working and others are proposed or in course of erection.

The Round Island beacon, now in operation, is situated near the lighthouse and employs a simple valve transmitter of moderate power working to an ordinary open aerial. The running of the station is entirely automatic, even to the replacement of the transmitting valves in case of failure; and the installation is maintained in working order by the staff of the lighthouse.

II. *DIRECTIONAL TRANSMISSION.*

(a) *The Beam System* — In recent years the arrangement of groups of antennae and reflector wires to give a concentrated beam of radiation has been developed to a considerable extent and is now coming into extended use for long-distance communication. If such a beam is made to revolve about a vertical axis, the device becomes analogous to a lighthouse, and signals are detectable at a distance only as the beam flashes past the receiver. By arranging a code of signals in such a way that they are transmitted automatically in succession as the radiating system rotates, then a vessel at sea would, in any position, receive a distinctive signal from which its bearing from the transmitter can be immediately ascertained. In order that such a scheme may be realised in practice, it is necessary that the dimensions of the aerial and reflector system shall be made reasonably small, which implies that the wave-length is correspondingly short (6 metres) and the limited range obtainable, together with the necessity of providing special short-wave receivers on those ships using the device, have probably accounted for the unpopularity of the system.

Inchkeith Station has been equipped with a parabolic reflector; at the South Foreland Station the antenna and reflector systems were in the form of plane grids or curtains.

(b) *Rotating Loops.* — Some experiments on the application of the Rotating Beacon

Transmitter to marine navigation (*) have been carried out on a rotating-loop beacon transmitter installed for the purpose at Fort Monckton, near Gosport. The beacon was identical with the type already in use by the Air Ministry.

The transmitter employs a vertical frame coil which rotates at a uniform speed about a vertical axis, and which is supplied with radio-frequency oscillations from a suitable valve.

Bearings are obtained on this transmitter by observing the time at which the signal minimum occurs after the transmission of a characteristic signal, which is sent when the plane of the coil is perpendicular to the geographical meridian. From a knowledge of the time of rotation of the coil, usually sixty seconds, the bearing of the receiver from the transmitter can be calculated. Since the accuracy of observation is directly dependent upon the speed of rotation it is necessary that this shall be maintained very uniform. A combination of a tuning fork and phonic motor has been found to provide a simple and efficient means of speed control giving an accuracy superior to that required in the practical use of the beacon. Since the timing is but an intermediate process in obtaining a bearing, it is possible for the observer to use a stop-watch or chronograph provided with a dial marked in the form of a compass card, with both degrees and points of the compass. By starting such a watch on the North signal and observing the position of the index hand at the occurrence of the signal minimum, the bearing can be read straight off the dial.

The object of the present investigation was to study the performance of the beacon when transmitting over land and sea, and particularly to ascertain the reliability for marine navigation purposes of wireless bearings taken with the aid of this beacon under a variety of conditions.

A calibration was carried out at fixed points in various directions around the beacon and at distances from it varying from 2 to 60 miles. This calibration showed that the bearings observed on the beacon are subject to a permanent deviation due to land effects, the magnitude of this deviation varying with the direction of transmission. Over the small open-sea sector available from Fort Monckton this permanent deviation is limited in value to 1 or 2 deg.

A series of tests, carried out in various cross channel ships between England, France and the Channel Islands, showed that for clear open-sea ranges up to 50 or 60 miles the observed wireless bearings from the beacon agreed with an extreme limit of 5 deg. with bearings estimated by other navigational methods; and in about 70 per cent of the cases the agreement was within 2 deg. In subsequent experiments it was shown that from ships at anchor at distances of 90 to 100 miles the wireless bearings observed in the daytime agreed within 4 deg. of the bearing calculated from the ship's position. At distances exceeding 60 miles, however, bearings from the rotating beacon were found to be subject to night effects similar to those experienced in wireless direction-finding. The errors resulting from these effects were not found to be very serious until the range of transmission exceeded 90 miles oversea, beyond which the errors of individual bearings amounted to 18 deg. Even in these curcumstances, however, a moderately accurate bearing can be obtained by taking the average of a series of consecutive readings over an interval of 10 or 15 minutes.

The minimum range at which night errors were encountered was considerably reduced when the transmission was entirely or partly overland. Within the range of reliable working, the accuracy of the observed bearings was found to be sensibly the same whether S. W. or I. C. W. transmission was employed at the beacon.

Taking the somewhat conservative figure of 50 miles as the reliable working range of the beacon for accurate bearings by both day and night, it was found that the present beacon gives adequate signal strength to a typical ship's receiver for observation at this range, except in the most unfavourable conditions of heavy interference.

In the course of the investigation a comparison has been made between the bearings observed on the rotating beacon and those obtainable with a direction-finder used in the ordinary manner. When used in fixed positions on land the direction-finder gives a somewhat superior accuracy, as it is not easy to obtain bearings on the rotating beacon to an accuracy of less than 2 deg. whereas a good land directing-finding station should give bearings reliable to 1 deg. As

(*) *See* The Journal of the Institution of Electrical Engineers. *Vol.* 66, *N*° 375 — *London, March* 1928, *pp.* 241-270.

is well known, however, the land direction-finding station is subject to errors due to local conditions which necessitate its frequent calibration, but the observed bearings from the rotating beacon have been shown to be largely immune from conditions local to the receiver. When the wireless bearings are taken on board a ship at sea, however, the case is somewhat different. The direction-finding bearing is taken relative to the direction of the ship's head, and its accuracy depends upon the steadiness of the ship and also upon the accuracy with which the ship's head is given by the compass reading at any desired instant. The bearing obtained by the rotating beacon is entirely free from this limitation and its accuracy is practically the same whether the ship is at sea, in motion or at anchor, or in dock. Furthermore, no correction or compensation corresponding to the quadrantal error associated with the ship direction-finder is necessary. The limitation of range of accurate bearings due to night effect has been shown, both theoretically and experimentally, to affect both systems to the same degree.

Investigations have been carried out at the Royal Aircraft Establishment, Farnborough, Hampshire, concerning application of R.A.F. rotating loop transmitter to aircraft navigation. A paper entitled "Rotating-Loop Radio Transmitters, and their application to direction-finding and navigation" by T. H. Gill and N.F.S. Hecht, Member, describes the various stages in the development of the beacon and refers to certain difficulties encountered and how they were met.

An appendix gives typical results obtained from tests on the ground and in aircraft during experimental trials.

From the results obtained, it is considered that bearings can be determined with an accuracy at least equal to that of any other wireless system of direction-finding. The work of the authors has been more particularly in connection with the use of the rotating-loop system for the navigation of aircraft, and for ranges up to 200 miles the results show that bearings can be determined with such accuracy as is required for the purposes of aerial navigation,

(c) *Course Setters.* — In concluding this survey, brief mention may be made of the so-called wireless course setter. The use of the directional transmitter has considerable advantages for the navigation of aircraft in that it can be installed at the home station, and the aeroplane has then merely to fly on a constant bearing line to arrive at its destination. To assist in this object an arrangement of a pair of loop transmitters was devised some years ago in Germany, the loops being identical and fixed together at some convenient angle. The loops may either be excited alternately at intervals of onee a second, or they may be excited together, but each loop is arranged to emit a Morse signal which is complementary to that given by the other.

When the receiver is located on a line bisecting the angle between the loops, both signals will be received of equal intensity and will thus be indistinguishable from each other. On either side of these bisecting lines the signal from one loop will predominate over that from the other. Thus, while such a scheme is only available over definite courses or air routes, it has the advantage over other directional methods in requiring no special apparatus or timing arrangements, and it gives an immediate indication of any departure from the course caused by drift from wind or tide. Such a method has received considerable attention in America, where it is pro posed to establish a network of wireless beacons along the main civil aviation routes.

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